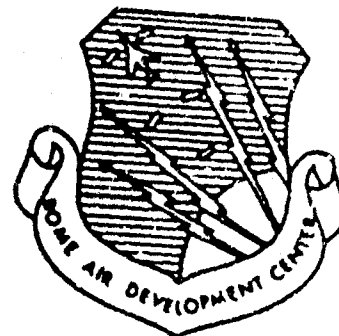


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RADC-TR-65-186, Vol. I
Final Report



ANTENNA LOBE SUPPRESSION

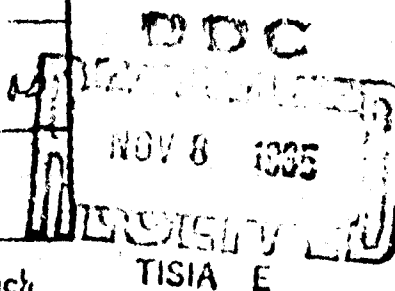
Volume I - Modification of Horn Antennas For
Low Sidelobe Levels

R. Lawrie
L. Peters, Jr.
C. Davis

TECHNICAL REPORT NO. RADC-TR- 65-186
October 1965

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ANTENNA LOBE SUPPRESSION

Volume I - Modification of Horn Antennas For Low Sidelobe Levels

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FOREWORD

This final report was prepared by the Ohio State University Research Foundation, Columbus, Ohio, under Contract AF30(602)-3269, Project No. 4540, Task 454003. The report was prepared in six volumes. The subtitles and brief abstracts of these volumes are included in the Form DD-1473 at the end of this report.

The RADC Project Monitor was Mr. Wayne Woodward (EMCVR).

This report has been reviewed and is approved.

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ABSTRACT

Four modified horn antennas with greatly reduced backlobes are described. The principal method of reducing backlobes consists of preventing the energy from illuminating the edges from which it is diffracted into the back regions. The mechanism for forcing energy away from these edges is the use of microwave absorber material, choke slots, and corrugated surfaces. An additional feature of these devices is an extremely smooth main beam with no discernible sidelobes.

A diffraction screen has also been constructed that makes use of this principle. Such screens should find application in the reduction of ground clutter in radar systems.

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MODIFICATION OF HORN ANTENNAS FOR LOW SIDELobe LEVELS

I. INTRODUCTION

It is well known that most antennas have sidelobe structures which can create interference. The general problem has been discussed in a previous report¹ and the sources of these sidelobes have also been described. This report is concerned with the reduction of the backlobes particularly in horn antennas.

In a pyramidal horn antenna the electric field vector is perpendicular to one pair of aperture edges, designated as E-plane edges. Furthermore, it has been shown that most of the backlobe structure of a horn is due to energy diffracted by the E-plane edges of the horn. In fact, the entire E-plane pattern of a particular horn has been accurately calculated by treating the diffraction from such edges as well as the geometrical optics field.² Thus, this report is concerned with methods of reducing the sidelobe and backlobe levels of a horn by controlling the illumination of the E-plane edges.

The basic approach is to prevent illumination of the E-plane edges by electrically modifying the walls of the horn having an E-plane edge as an element. The modification is achieved by one of three methods: by lining the walls with microwave absorber, by a series of choke slots cut into the walls, or by creating a reactive surface at the walls. In this investigation the reactive surface is a corrugated surface, a section of which is illustrated in Fig. 1.

The analysis of an infinite corrugated surface may be considerably simplified by making the following assumptions:

- (1) The slot walls (teeth) are vanishingly thin.
- (2) Only the TEM mode in the slots is reflected from the base of the slots. The higher order modes are attenuated before reaching the base.

The second assumption is equivalent to requiring that the slot width (g) be small compared with both the free-space wavelength and the slot depth (d). For such a surface, results obtained by Elliott³

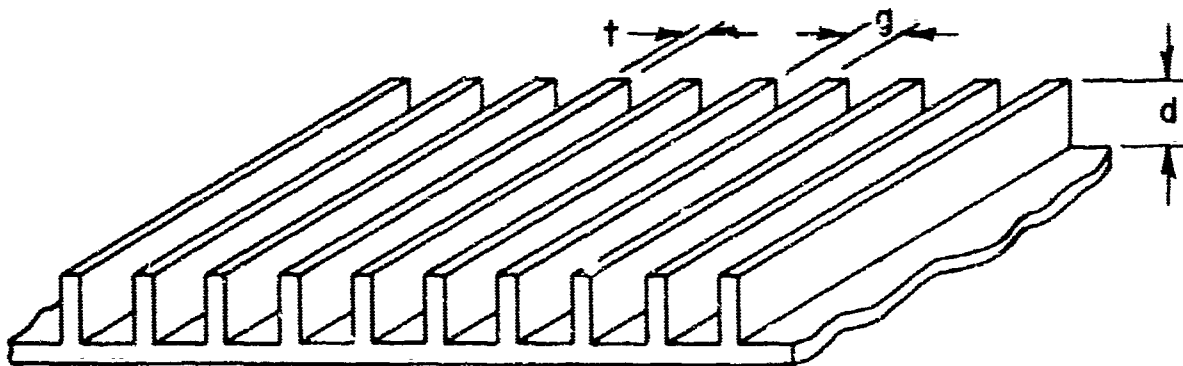


Fig. 1. Section of corrugated surface.

can be used to show that the reactance of the surface is given to a good approximation by

$$(1) \quad x = \frac{g}{g+t} \sqrt{\frac{\mu}{\epsilon}} \tan k_0 d$$

provided that

$$\frac{g}{g+t} \approx 1.$$

This condition is satisfied if $t \leq g/10$ and the second assumption is valid for $g \leq \lambda/10$.

The surface reactance must be capacitive so that the surface will not support a surface wave, or, from Eq. (1), $\lambda/4 < d < \lambda/2$. Of course d may be within some odd integral multiple of this interval. Hurd⁴ has shown that the cutoff depth d_c depends to some extent on the slot width (g). However, curves given by Hurd indicate that for $g \leq \lambda/10$ the cutoff region is approximately $\lambda/4 < d < \lambda/2$.

It has been shown that choke slots cut into the walls of a horn can significantly reduce the back lobe level.⁵ For the horn discussed in Reference 5 a reduction of 24 db was obtained using six slots in each of the two walls.

Kay⁶ has developed a similar horn antenna, designated as the scalar feed, which is a circular horn with the type of bent choke slot shown in Fig. 2. Kay designates this as a corrugated structure. However, his choke slots are separated by nearly half a wavelength and thus do not meet the condition of Eq. (1). Nevertheless the results obtained by Kay are impressive and his backlobes are more than 30 db below the pattern maximum.

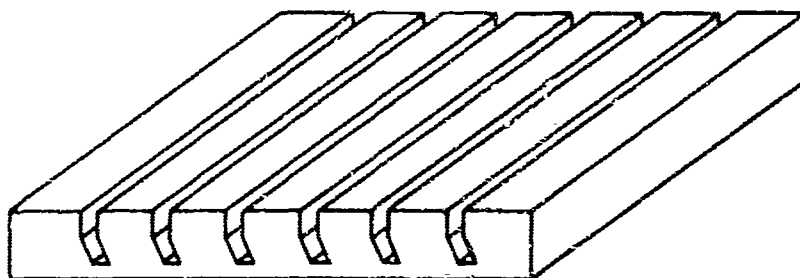


Fig. 2. Array of bent choke slots.

Microwave-absorbing material applied to the walls of a horn produced a significant reduction in the backlobe level. Unfortunately it also produced a serious reduction in the overall gain of the antenna.

Experimental results obtained with the three methods described are discussed in detail in the following section.

Finally, through the use of a corrugated structure a significant increase in the effectiveness of a screening fence has been achieved. A discussion of the corrugated screening fence is presented in the appendix.

II. MODIFIED HORNS

Four modifications of horn antennas are considered in this section. The first is a large horn the walls of which have been lined with Eccosorb, type AN microwave absorber. The second is a thick-walled small horn with an array of choke slots in the walls. It is hereafter designated as the choked horn. The third horn is designated as the small corrugated horn. The fourth horn is the large corrugated horn which has the same interior dimensions as the absorber-lined horn. The choke slot version of these horns is discussed in Reference 5.

A. The Absorber Lined Horn

The horn employed for this portion of the investigation is an X-band, pyramidal horn, $13\frac{1}{2}$ " high with a $9" \times 9"$ aperture. The $\frac{1}{4}$ "-thick absorber is placed along the walls of the horn so that it protrudes slightly beyond the E-plane edges. The resultant pattern, superimposed over the unmodified horn pattern, is shown in Fig. 3. The 13-db change in the beam maximum results from energy loss in the absorber. Smoothing of the main beam and reduction of the backlobes with respect to the main beam is the result of the elimination of E-plane edge illumination.

In any communication system, the severe loss in gain due to energy loss in the absorber would completely nullify the improvement in back-lobe and sidelobe levels.

In view of the results described in the following sections no attempt was made to improve the results obtained with the absorber-lined horn.

B. The Choked Horn

A small choked horn was constructed with a designed aperture $3\frac{1}{2}$ " square and with a 92° flare angle. The E-plane walls are $5/8$ " thick with four evenly spaced choke slots per wavelength. The choke slots are designed to be $3/8$ wavelength deep at 10 Gc.

It is desirable to have a controlling parameter for all antenna measurements. With the choked horn this is easily and accurately obtained by placing strips of aluminum tape over the chokes and painting over the chokes with silver paint. This leaves a horn with smooth and thick E-plane walls whose effect on the antenna pattern has already been investigated.²

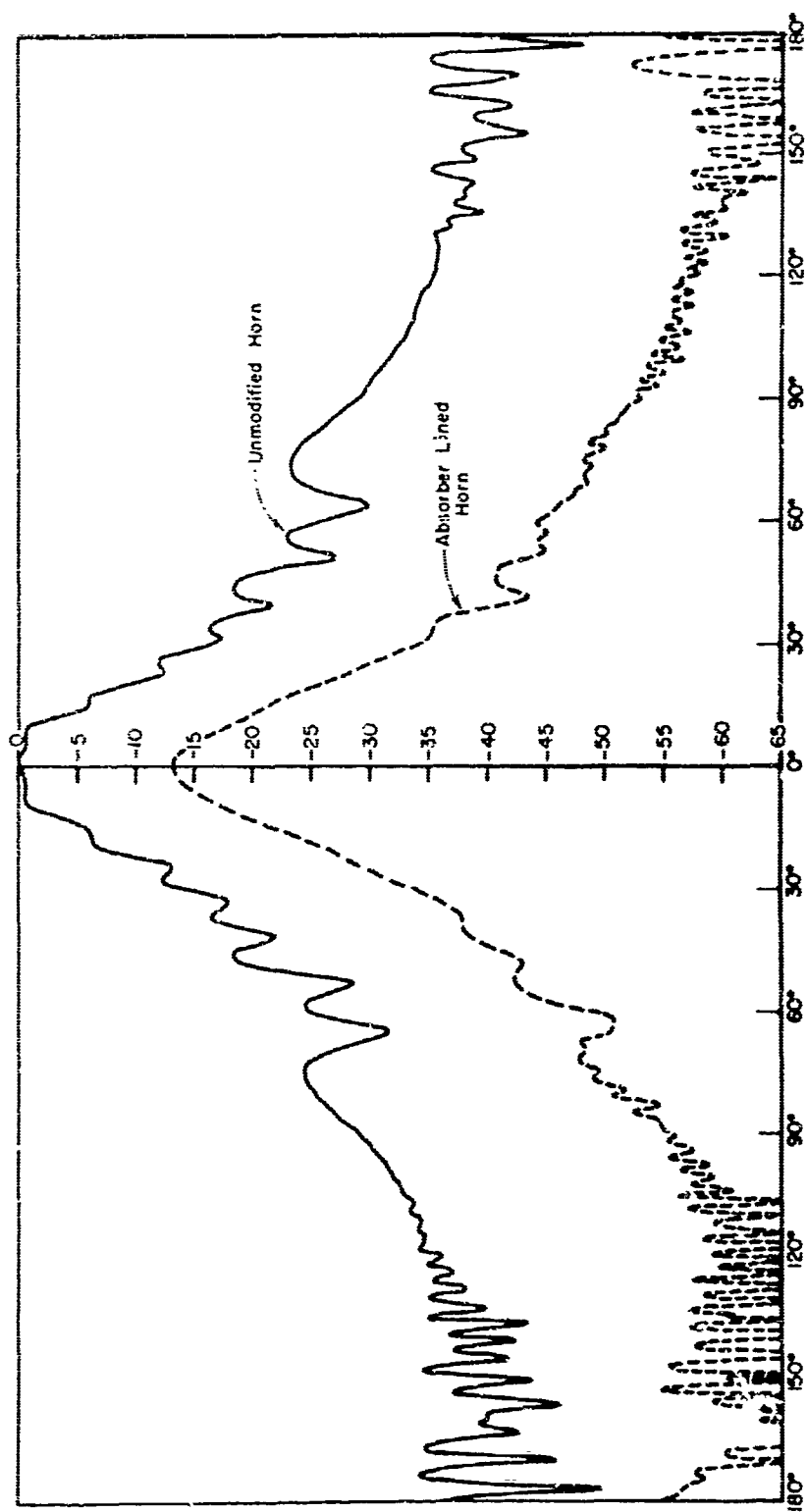


Fig. 3. E-plane patterns of the absorber lined horn and the unmodified horn measured at 10 Gc.

The behavior of the backlobe level of the antenna relative to the maximum is of primary interest. These data are plotted as a function of frequency in Fig. 4 where it is compared to the relative backlobe level of the control horn. The backlobe level of the control horn is seen to be essentially a constant over a nearly 2:1 bandwidth, while the backlobe level of the choked horn is 3 db below that of the control horn at the higher frequency and 12 db below the control horn at the lowest frequency measured. The lowest frequency used was 6.6 Gc; the choke depth at that frequency is $\lambda/4$.

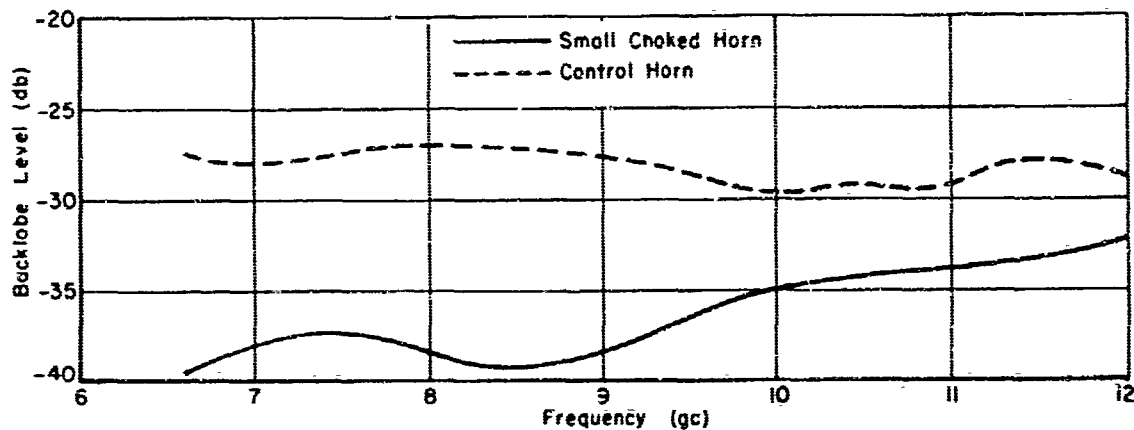


Fig. 4. Ratio of backlobe to mainlobe level of the small choked horn and the control horn as a function of frequency.

The effect of the chokes on the main lobe is compared with the control antenna in Fig. 5, where beamwidth is plotted vs frequency. It is felt that due to irregularities in the pattern of the control horn at the higher frequencies, the 6 db beamwidth is a more representative parameter than the 3 db beamwidth. A marked independence of frequency in the H-plane is seen, as might be expected; and a marked dependence on frequency in the E-plane is found, with a minimum beamwidth occurring at approximately 9 Gc. This is in contrast to the beamwidth of the control antenna in the E-plane which is consistently greater than the choke-slot antenna.

The effectiveness of the chokes in rejecting energy from the E-plane walls can also be seen by probing the $3\frac{1}{2}$ " aperture in both the E- and H-planes. The aperture distribution for the control horn is shown in Fig. 6 and may be compared with that of the choked horn

shown in Fig. 7. The aperture distributions shown were obtained at 7.1 Gc. The chokes produce a symmetrical distribution in the E- and H-planes, which is substantially the same as the H-plane distribution of the control horn.

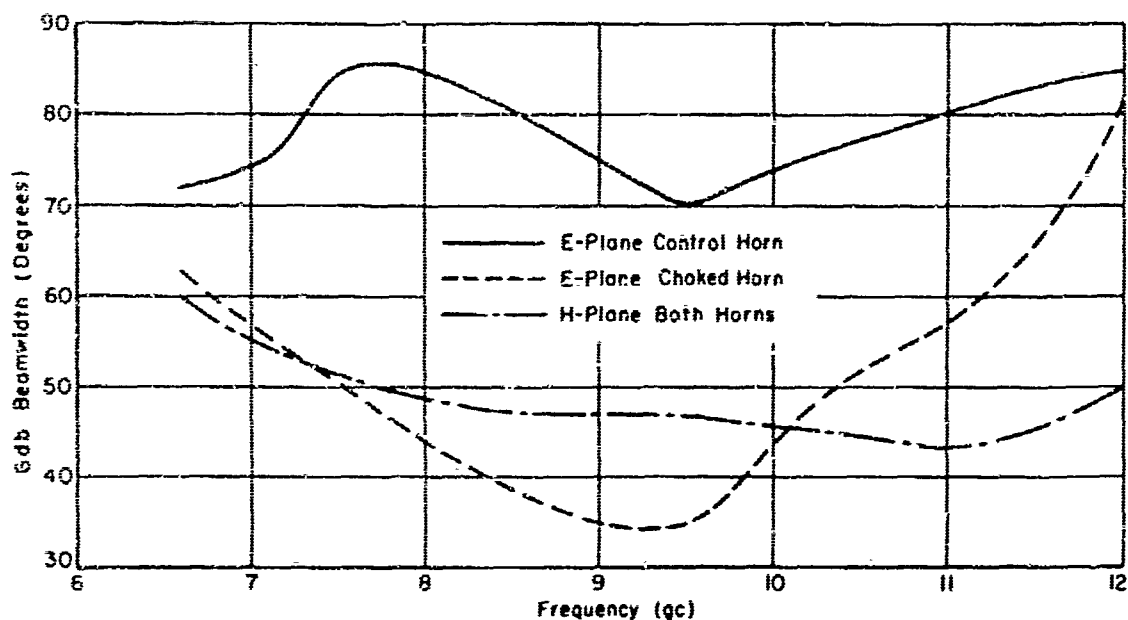


Fig. 5. 6 db beamwidth of the choked horn and control horn as a function of frequency.

Figure 8 and Fig. 9 compare the E-plane pattern of the control horn and the choked horn at 6.6 Gc and 12.0 Gc respectively. Note that at 12.0 Gc the main beam of the control horn has begun to split into two lobes. This splitting represents a limitation on the bandwidth of the horn. Splitting of the main beam of the choked horn does not occur at 12.0 Gc. Thus the splitting may be attributed to edge effects which have been eliminated by the choke slots. Therefore, the choke slots have increased the bandwidth of the horn.

C. The Small Corrugated Horn

Another small horn was constructed with a $3\frac{1}{2}$ " square aperture having an internal E-plane wall structure of many slots per wavelength (about 4 times that of the choked horn, or 15 per wavelength at 10 kmc). This new horn was designed with a flare angle of 50° to compare with small horn patterns previously assembled.

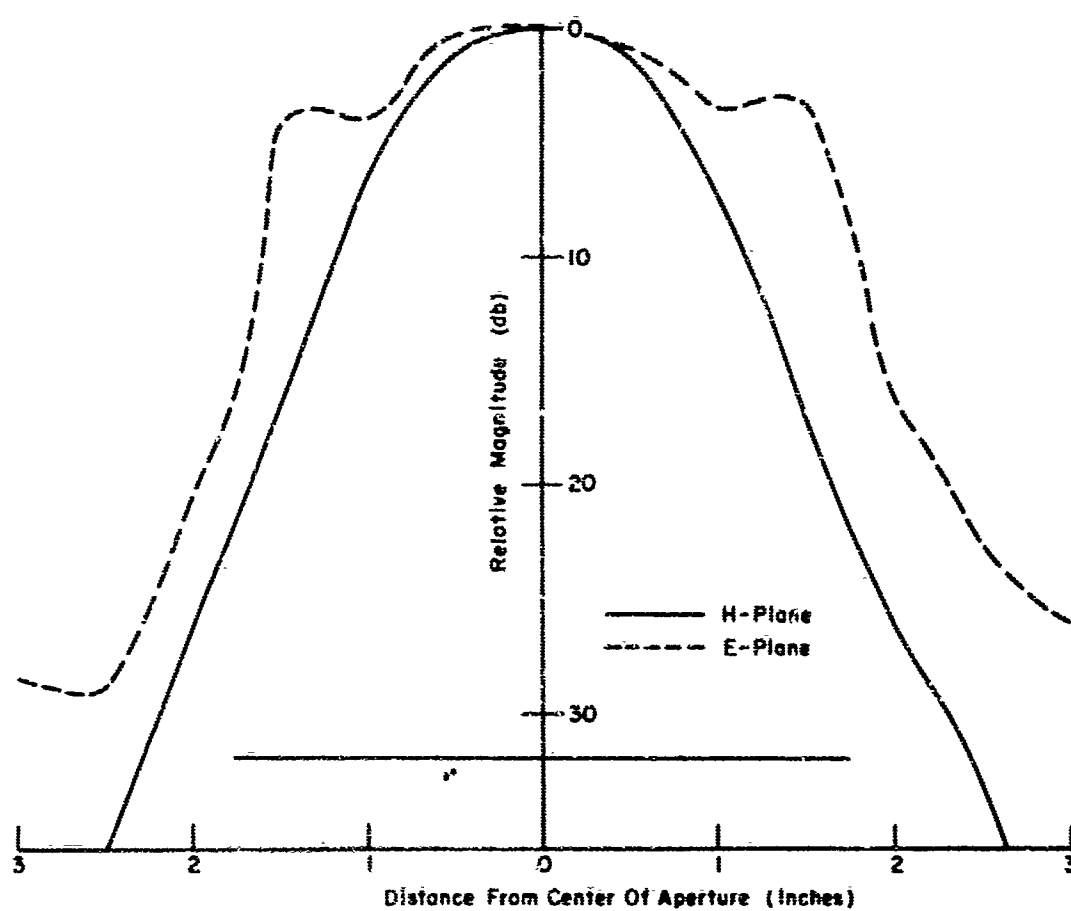


Fig. 6. Aperture field distribution of the control horn at 7.1 Gc. Measured 1/16" in front of aperture plane.

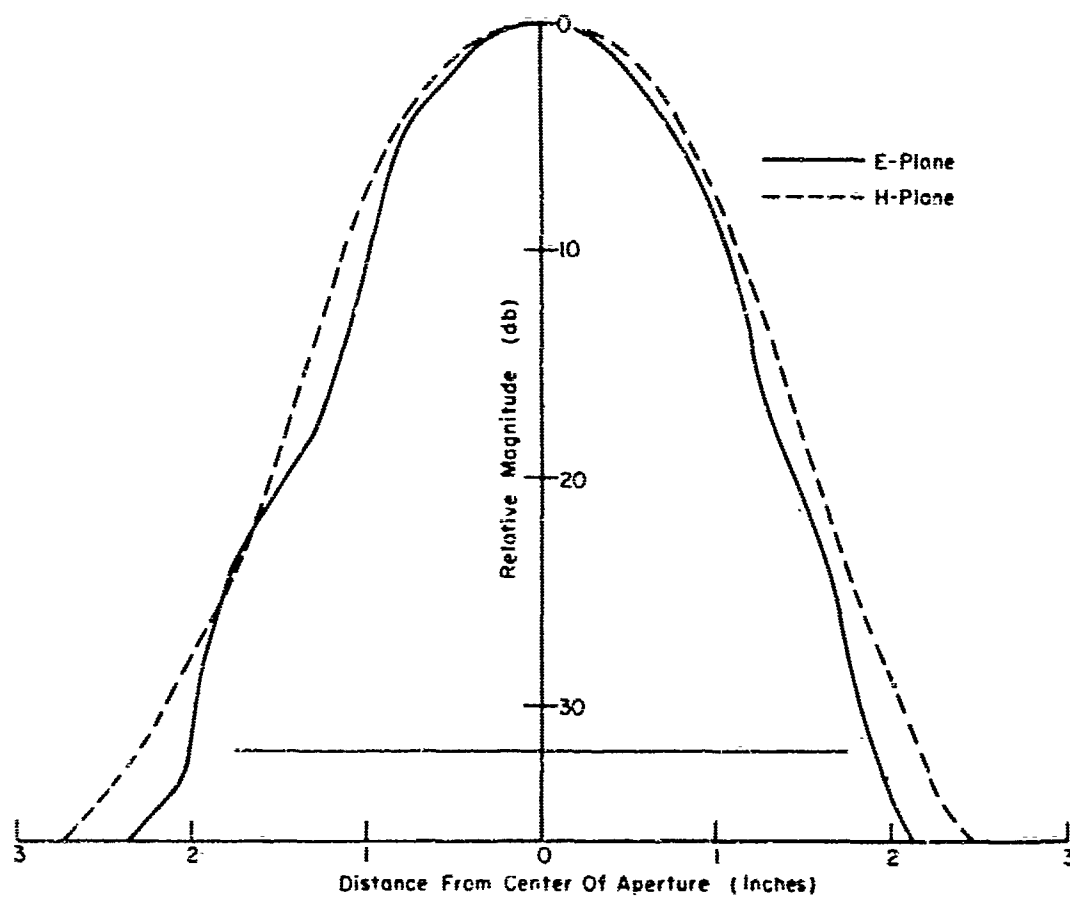


Fig. 7. Aperture field distribution of the choked horn at 7.1 Gc. Measured $1/16$ " in front of aperture plane.

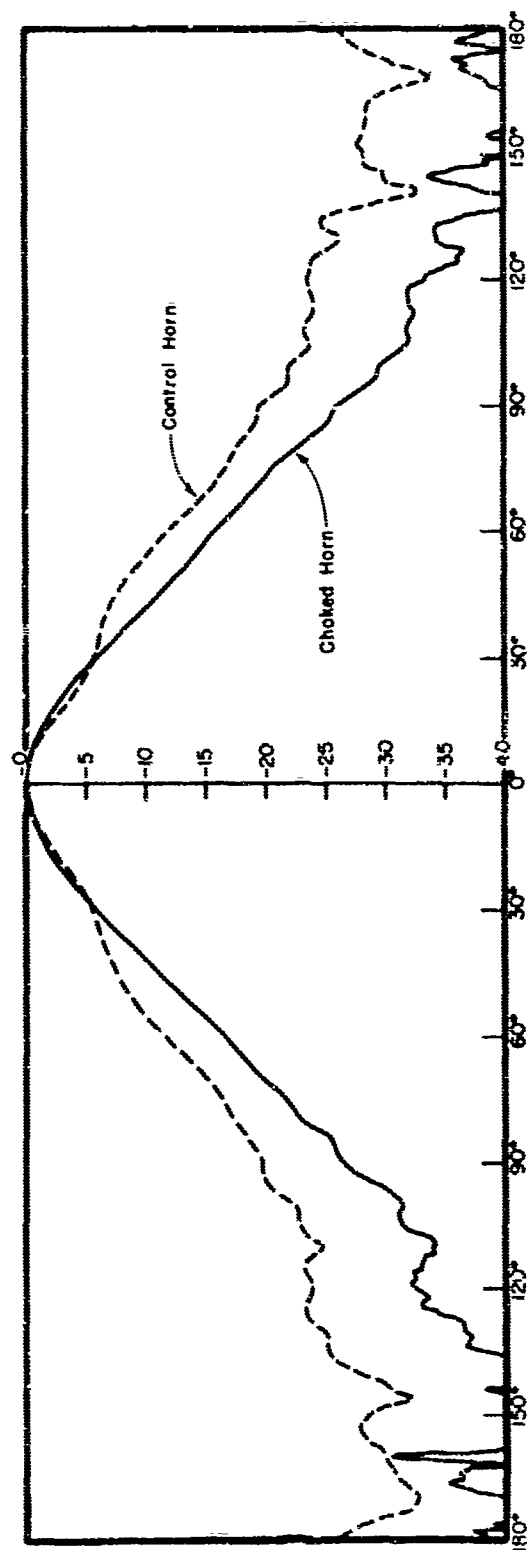


Fig. 8. E-plane patterns of the control horn and the choked horn measured at 6.6 Gc.

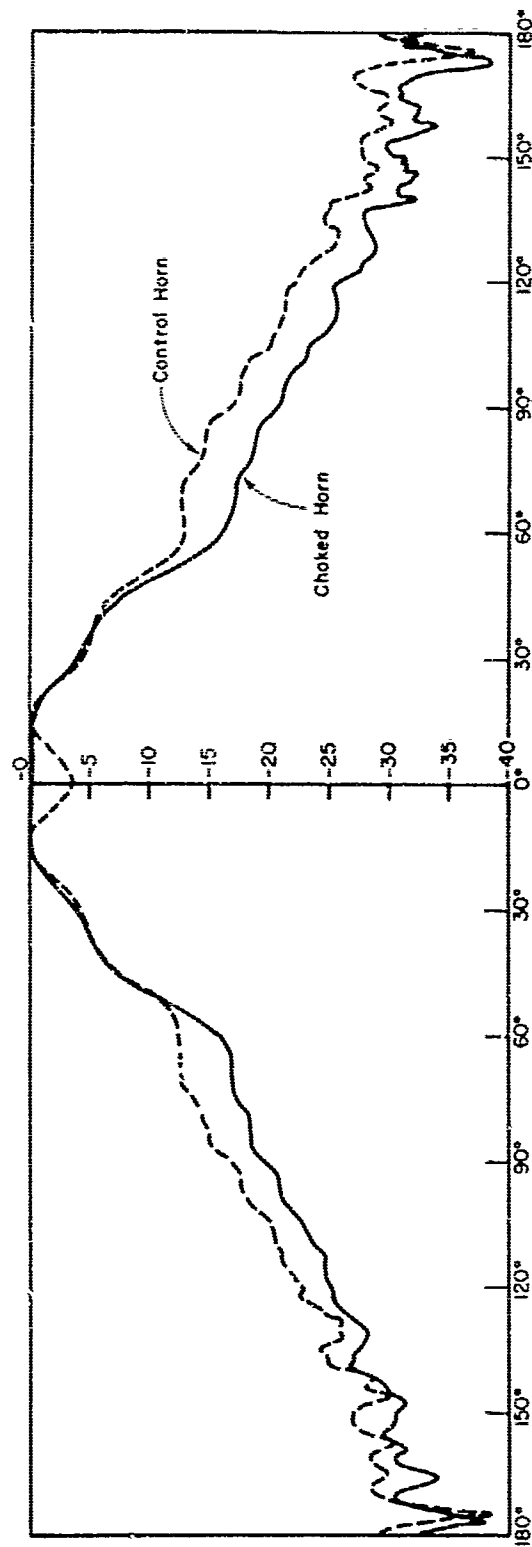


Fig. 9. E-plane patterns of the control horn and the choked horn measured at 12.0 Gc.

The control horn for this structure is again the prototype covered with aluminum tape and paint. The curves of backlobe level vs frequency for both antennas are shown in Fig. 10. From this a definite passband within which the corrugated walls have their greatest effectiveness can be seen from 8 to 14 Gc. The average backlobe is found at -42 db below the main beam, while the beamwidth at these frequencies ranges from ¹⁸16° to 22°. The backlobe level of the control horn for these same frequencies varies, with an average of -32 db, or 10 db above the corrugated horn.

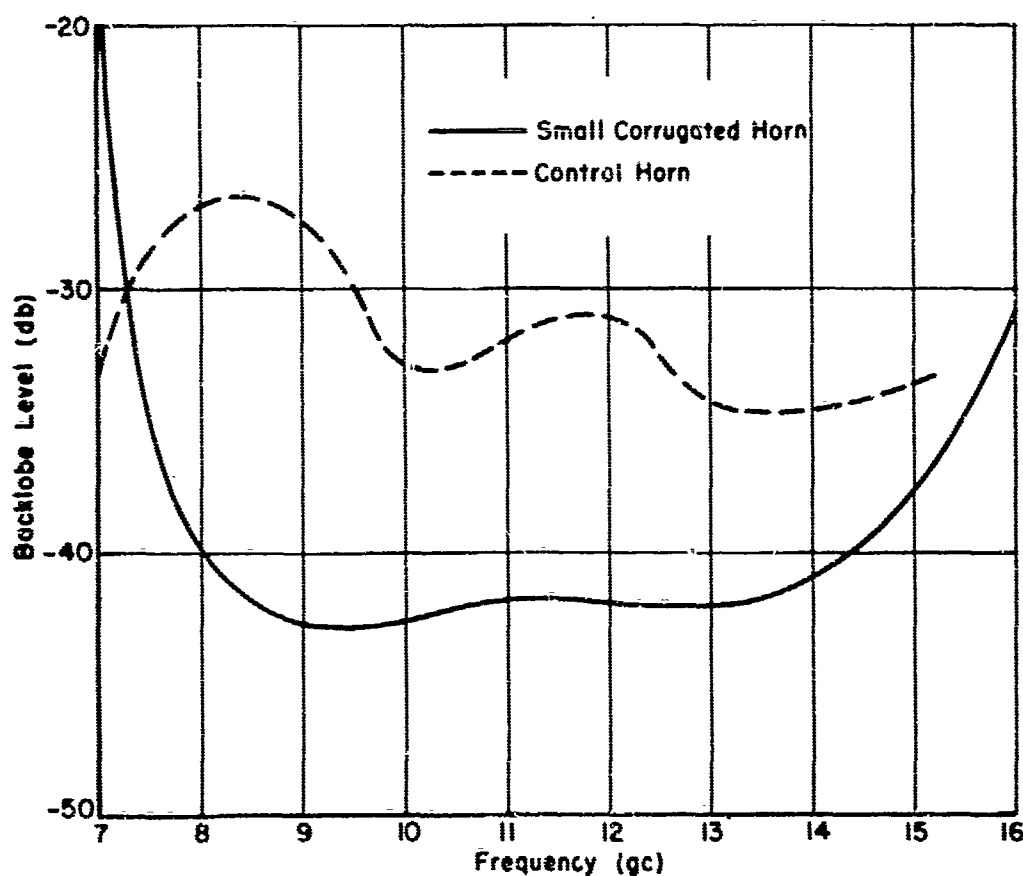


Fig. 10. Ratio of backlobe to mainlobe level of the small corrugated horn and the control horn as a function of frequency.

Figure 11 shows the 3 db beamwidth-vs-frequency curves of the corrugated horn and the control horn. The two are similar but displaced by about 4.2° . In contrast with the choked horn, the corrugations have resulted in an increase in beamwidth.

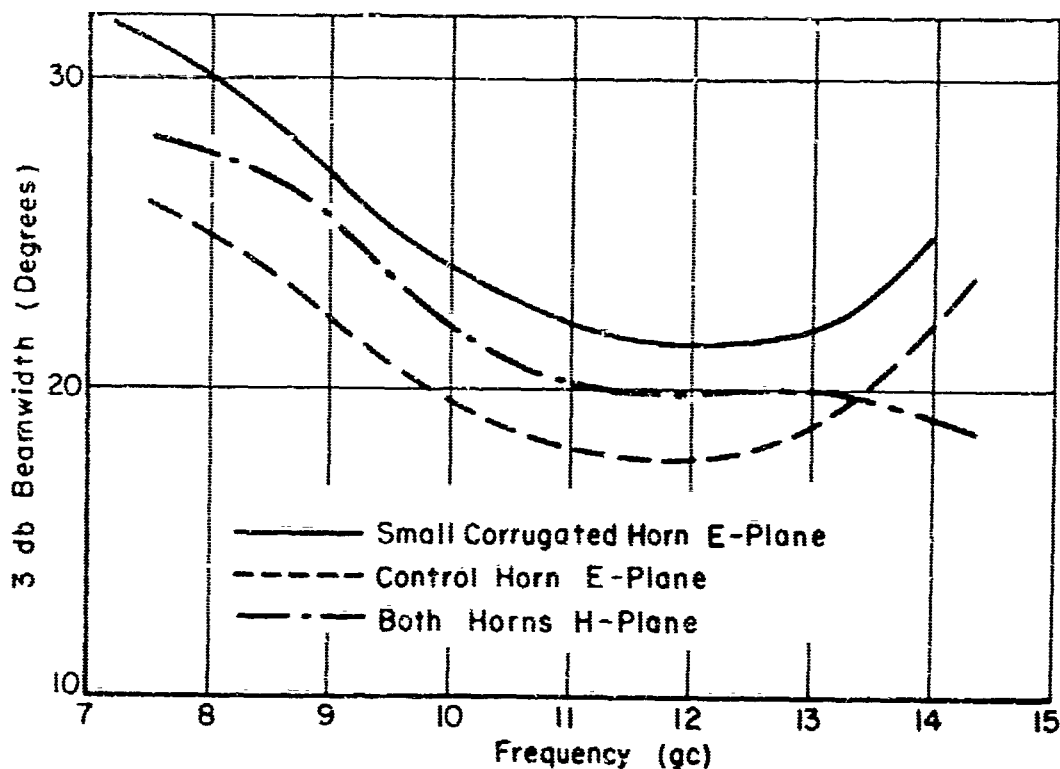


Fig. 11. 3 db beamwidth of the small corrugated horn and the control horn as a function of frequency.

The E-plane pattern of the small corrugated horn superimposed on the E-plane pattern of the control horn is shown in Fig. 12. Both patterns were obtained at 10 Gc.

D. The Large Corrugated Horn

The horn employed in this phase of the investigation is a thick-walled pyramidal horn having a flare angle of 34° , a height of 5.95", and a 9.7" X 9.7" aperture. The corrugated surface is machined into the proper walls from within 1" of the throat to the mouth. The large

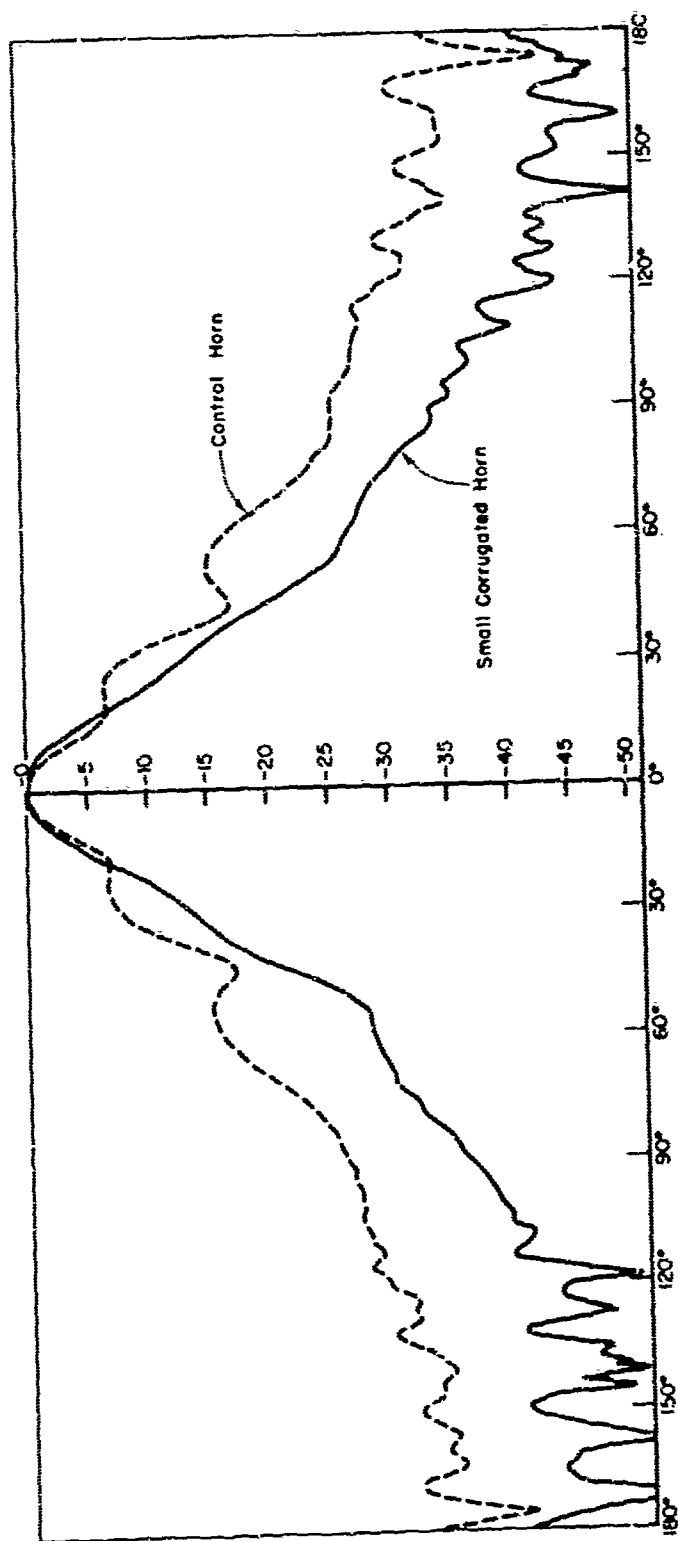


Fig. 12. E-plane patterns of the small corrugated horn and the control horn measured at 10 Gc.

control horn is a thick-edged horn having the same interior dimensions. The E-plane pattern of the large control horn is shown in Fig. 13. The E-plane pattern of the large corrugated horn is shown in Fig. 13. The H-plane patterns of the large corrugated horn are nearly identical to that of the large control horn and are not shown. These patterns were obtained at 10 Gc.

The approximate directivity of the large control horn is $21\frac{1}{2}$ db, while that of the large corrugated horn is $22\frac{1}{2}$ db. The change in directivity is caused by the reduction of the E-plane beamwidth and by the removal of the saddle in the E-plane pattern of the control horn. The saddle is attributed to edge effects which are removed by the action of the corrugated surface.

The backlobe of the large corrugated horn is 57 db below the main beam. Thus it is 27 db better than the difference between the main and backlobes of the control horn.

Initial measurements of the E-plane pattern of the large corrugated horn indicated severe interference effects throughout the back hemisphere. It was found that the primary source of the interfering signals was leakage through the waveguide joints and components (i. e., detector, attenuator). A rearrangement of components and the judicious application of aluminum tape and metallic paint greatly reduced the interference. The remaining interference is attributed to scattering from various structures in the vicinity of the pattern range.

III. CONCLUSIONS

The use of choke slots or a corrugated structure in the walls of a horn antenna have been demonstrated to be effective methods of reducing the backlobe level of the horn. The use of corrugated surfaces produces a greater improvement than the choke slots but results in a slight increase in beamwidth. The attainable reduction in backlobe level is limited by diffraction from the wedge formed by the waveguide and the wall of the horn to the edge of the opposite wall. It was found that the useable bandwidth of the modified horns is at least as great as the bandwidth of the transmission line feeding the horn.

The type of modified horns discussed in this report may find many applications, such as use in pattern ranges and radar cross section ranges. As Kay⁶ notes, the application of this type of antenna as a feed will result in the good low-temperature performance

required in many modern systems, and will also be useful in the reduction of interference between various systems. One can envision further uses for corrugated surfaces, such as application to screening fences (see Appendix), for the reduction of interference and ground clutter in radar systems. Furthermore, corrugated surfaces might find application in the isolation of an antenna from surrounding surfaces, such as an air frame; however, such applications require further study.

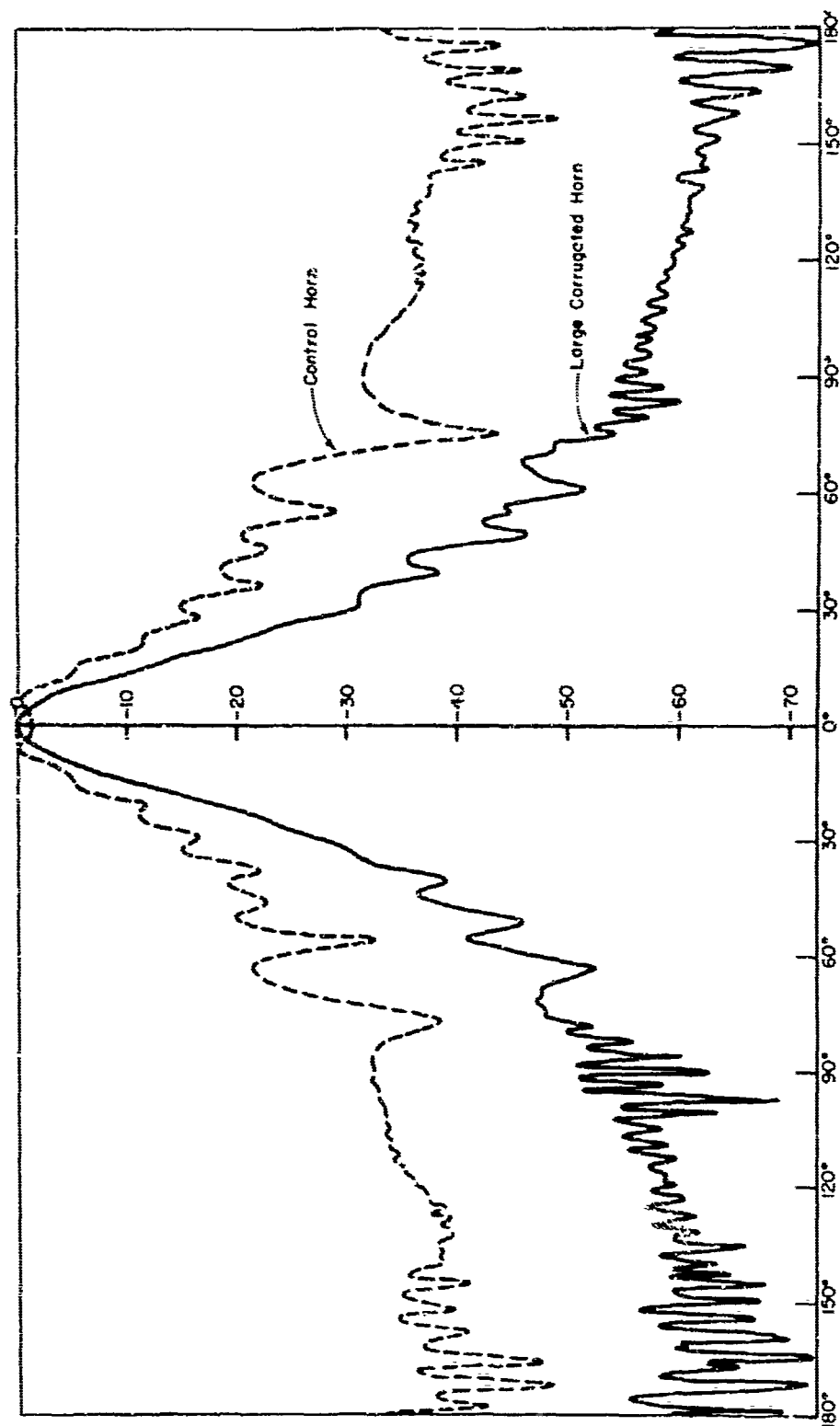


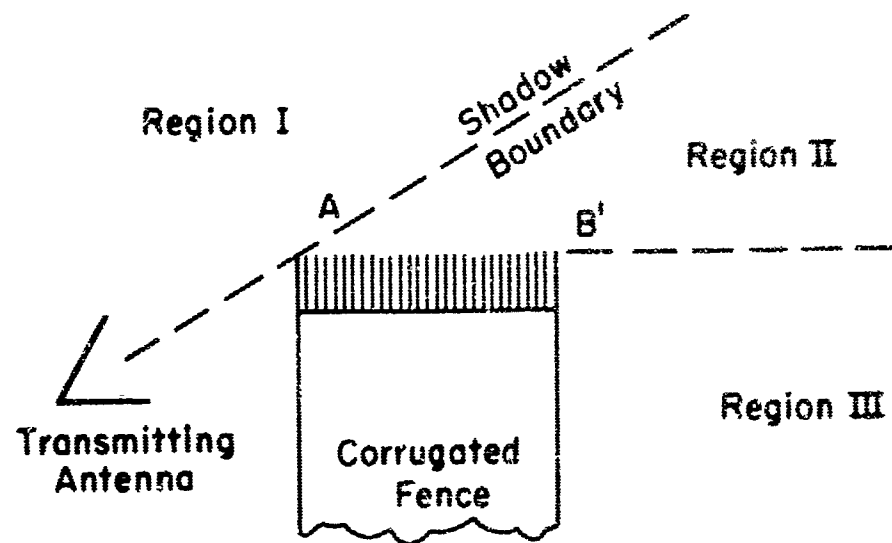
fig. 13. E-plane patterns of the large control horn and the large corrugated horn measured at 10 Gc.

APPENDIX THE CORRUGATED SCREENING FENCE

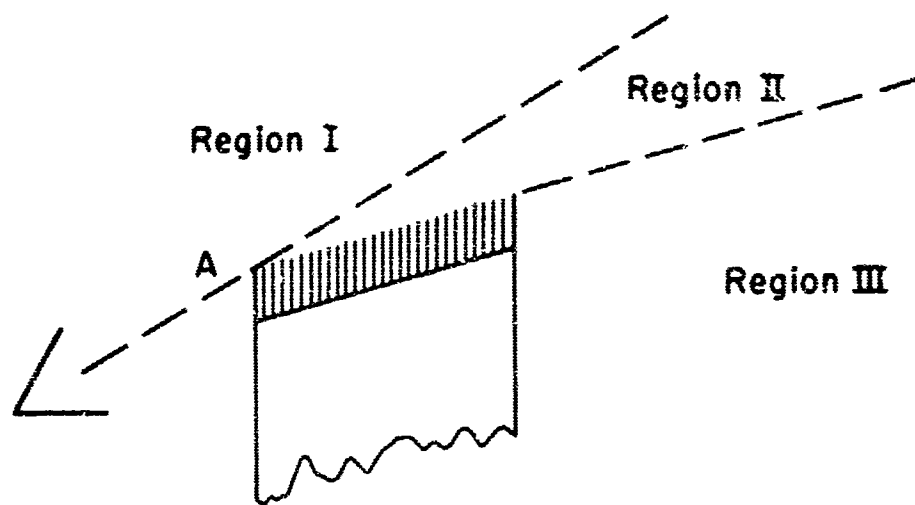
The use of the corrugated screening fence for the reduction of ground clutter is illustrated in Fig. 14. The operation of the screen would require that the reflecting objects lie in region III. The transmitted energy would be diffracted by corner A into regions I and II. The dominant energy in region I would be the direct transmitted energy. The fields on the shadow boundary would be $\frac{1}{2}$ the field without the screen. The fields diffracted by corner A decay as the observation point is moved from the shadow boundary into region II (see Fig. 14). This component of field may be computed by use of the solution for the 90° wedge.² In addition, a wave propagates over the top of the surface to corner B where it is diffracted into region III. There is little radiation from this wave, provided the top surface is smooth. The introduction of the corrugations forces this wave off the surface and most of this energy is radiated into region II. Thus the energy incident on the object in region III is significantly attenuated, but the energy level in region II has been increased. There is, of course, no restriction requiring the fence to be vertical or composed of 90° corners. The restriction is that the antenna does not directly illuminate the corrugated surface and that the reflecting object creating the ground clutter must lie in region III. Another possible configuration is shown in Fig. 14b. Thus it is possible to increase the shielded region (region III) but the operating region of the scanning antenna is fixed by the shadow boundary established by corner A. This scanning angle may be made to approach ground level by further separating the antenna and the fence. The radiating mechanism of the antenna must be considered to establish the location of the shadow boundary; as illustrated in Fig. 15

To ensure proper operation of the corrugated surface all the radiating portion of the antenna must be located such that it does not directly illuminate the corrugated surface, as illustrated by ray 1 in Fig. 15. If this condition is not satisfied the magnitude of the signal diffracted by corner B by any such direct illumination must be considered. The proper operation of the antenna, on the other hand, is restricted by the condition imposed by ray 2. This restriction may be relaxed at the expense of altering the antenna pattern.

It should be further noted that the antenna polarization should be such that the wall normal to the E vector is corrugated. The other wall may or may not be corrugated. The attenuation is essentially the same.



(a)



(b)

Fig. 14. Illustration of corrugated screening fence for the reduction of ground clutter.

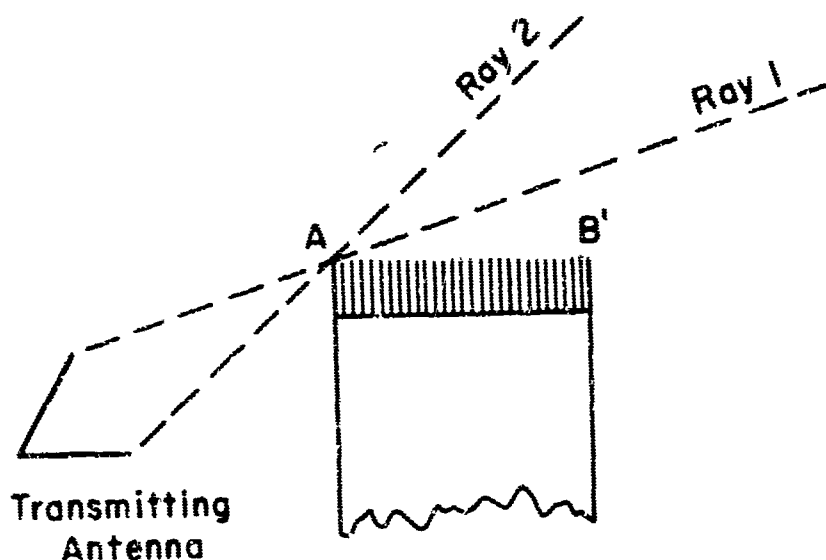


Fig. 15. Ray determination of shadow boundary.

Magnitude of Attenuation

The magnitude of attenuation of the signal into region III has been determined by means of experiment. Calibration of the attenuation has been obtained with respect to a screening fence of the same dimensions but without corrugations. The reduction obtained by this fence may be obtained by use of the edge diffraction concepts. This has not been done as yet. A square screen approximately 10λ high has been used in direct transmission experiments to determine the attenuation obtained. The width of the corrugated surface is approximately 3.5λ . A curve showing the attenuation obtained in this manner is illustrated in Fig. 16. The attenuation in db would be doubled to determine the improvement in ground clutter because of the two-way path involved. The position of the probe was varied but no significant effect is noted when the non-corrugated structure of the same dimensions was used to calibrate the result. It must be emphasized that the results shown in Fig. 16 represent the improvement in shielding obtained over the non-corrugated screen of the same dimensions. This structure in itself would offer significant screening, but the numerical evaluation of it would be a complex function of antenna position and probe position in terms of angle and range, hence no single numerical factor would suffice. One notes however that the field on the shadow boundary (see Fig. 14)

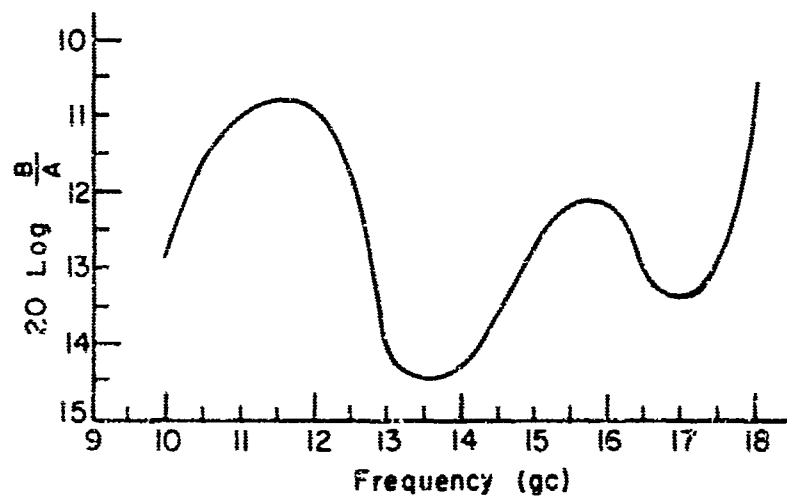
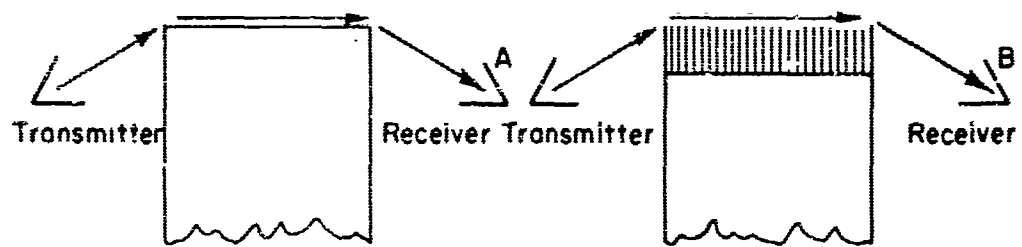


Fig. 16. Additional attenuation obtained by corrugating a screen fence.

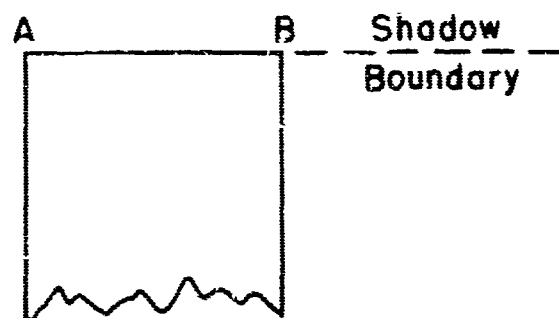


Fig. 17. Illustration showing shadow boundary.

would be 6 db below the field without the screen and would attenuate rapidly as one progresses into the region II. The field on the shadow boundary illustrated in Fig. 17 is one half of the field if corner B were not present. Thus another 6 db would be introduced and as one progresses into region III additional attenuation would appear. For a two-way transmission to reduce ground clutter, there would thus be a reduction of at least 24 db because of the presence of the two wedges. The attenuation caused by the corrugation, which is double that given by Fig. 16, should be added to this 24 db to obtain the total reduction of ground clutter obtainable by this method.

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by considering contributions from both the principal H-plane and E-edge diffractions.

e. Volume V, entitled "Grated Reflector Antennas for Spurious Radiation Reduction" A method of reducing the radio frequency interference resulting from radiation at spurious frequencies by utilizing the frequency sensitivity of grating reflectors is examined. A technique is presented whereby the attenuation in a radial-wedge waveguide operating beyond cut-off may be calculated.

f. Volume VI, entitled "Diffraction by Conducting Walls of Finite Thickness" Diffraction of thick walls is computed by the superposition of wedge diffractions. Thick wall diffraction is applicable to reduction of backlobe radiation aperture antennas. In this regard, the electromagnetic compatibility of a thick wall for use of typical horn antennas is discussed.

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13. ABSTRACT		
The title and a brief description of each of the six volumes follow:		
a. Volume I, entitled "Modification of Horn Antennas for Low Sidelobe Levels". Four modified horn antennas with greatly reduced backlobes are described. The principal method of reducing backlobes consists of preventing the energy from illuminating the edges from which it is diffracted into the back regions.		
b. Volume II, entitled "The E-Plane Radiation Pattern of an Antenna Model for Horn Antennas". Diffraction theory is used in analyzing the radiation characteristics of typical horn antennas. The far-side-lobe and back-lobe radiation has been solved without employing equivalence principles which are impractical in the problem.		
c. Volume III, entitled "Radiating Mechanisms in a Reflector Antenna System". The corrugated horn represents a good feed in a reflector antenna system. It is used in this report as a feed for an offset parabolic antenna. The various radiation mechanisms are discussed and means are suggested for further reduction of undesired radiation.		
d. Volume IV, entitled "The H-Plane Radiation Pattern of Horn Antennas". Diffraction theory is used to formulate the H-plane radiation pattern of a horn antenna. Excellent agreement between computed and measured patterns is achieved.		

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Pyramidal Horn Offset Parabolic Antenna Slab Parabolic Reflector Antenna Pyramidal Horn with "cut-off" Corrugated Surface as the H-plane wall						

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